Microwave-Regenerated Particulate Filter Durability Testing in Automobiles

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Objectives

- Develop and demonstrate a low-cost, yet very durable microwave-regenerated particulate filter system that captures and destroys more than 95% of the particulates produced by a diesel engine.
- Improve the uniformity and heating efficiency of the microwave field.
- Conduct on-road vehicle durability testing of the microwave filter system.

Key Milestones

- Improved microwave field uniformity in the filter cartridge from heating 10% of the filter to heating 60% of the filter cartridge volume.
- Improved ceramic fiber filter media burst strength from 1 to 6 lb/in.^{2}, a 500% improvement in mechanical durability.
- Demonstrated a diesel particulate matter destruction efficiency of greater than 95% on the stationary 1.9-L test cell over the operating range of the engine.

Approach

FY 2000 filter problems were principally caused by non-uniform microwave heating of the filter cartridge. Finite-element computer programs were used to model the microwave heating of the silicon carbide filter cartridge. The results of the computer modeling were applied to refine the filter cartridge and microwave component configurations. A microwave engineering effort was conducted to reduce the size of the microwave source components. Calculations of the mechanical stresses on the filter cartridge by the diesel exhaust showed that the current 1.0 psi burst strength of the ceramic fiber filter media needed to be increased to at least 3.0 psi to survive the full-load operating conditions of a diesel engine. A 3-month materials science matrix experiment program was conducted to increase the mechanical strength of the ceramic fiber filter media. This program addressed such variables as ceramic papermaking, binder addition techniques and furnace processing. The microwave and materials improvements were incorporated into an experimental prototype. This prototype system was tested on a 1.9-L stationary diesel engine test cell at Oak Ridge national Laboratory. With satisfactory results from these tests, the on-road diesel vehicle microwave filter systems were designed. Two vehicles were selected for on-road testing of the microwave filter system. Instrumentation was designed,

fabricated, and tested to continuously monitor the backpressure resulting from carbon particulate accumulation on the filter, the exhaust flow, and the temperature of the exhaust during vehicle operation. The instrumented filter exhaust systems were installed on a Ford F-250 7.3-L diesel pickup (Figures 1 and 2) and a Volkswagen Jetta 1.9-L diesel car provided by DOE (Figures 3). The Ford truck is being tested under routine highway driving conditions for approximately 6,000 miles. The filter will be removed and microwave-regenerated in the laboratory to understand the effects of microwave heating on the particulate loaded cartridge. The Volkswagen Jetta is being equipped with and on-board microwave regeneration system. This vehicle will be driven for 7,000 miles under controlled test-track conditions by the Transportation Research Center near Columbus, Ohio. It will be subjected to FTP-cycle chassis dynamometer emissions testing at periodic intervals. The data from both on-road tests will be used to improve the performance of the microwave-regenerated particulate filter, verify system durability, and precisely quantify the fuel penalty resulting from filter operation.

Results

The microwave field finite-element program analysis improved the heating efficiency of the filter cartridge from 10% of the filter volume in FY 2000 to over 60% in FY 2001. The mechanical strength of the ceramic fiber media, at the conclusion of the 3-month experimental matrix optimization program increased from 1.0 psi to 6.0 psi. Calculations have shown that 3.0 psi would be adequate for a typical diesel exhaust stream. Analysis of the materials matrix data shows that further improvement to 10 psi is attainable. The diesel engine manufacturers have insisted that 95% of particulate matter destruction is necessary to comply with the EPA Tier II requirements. Data on the FY 2001 microwave filter system improvements from the diesel 1.9-L engine test cell demonstrated an average particulate removal efficiency of 97%, over a spectrum of normal engine operating conditions. Preliminary road testing of the filter on the Fort 7.3-L truck proved that the filter could survive the full loading of 1,000 ft^3/minute of exhaust flow without mechanical failure. The complete results of the on-road testing will be available in September, 2001.

Conclusions

The microwave-regenerated filter was introduced to the DOE PNGV program in FY 1999. The technology has met or surpassed its milestone goals each year. The automotive industry must now be convinced that it is a potential solution to future particulate emissions standards. Their principal remaining question is the durability of the microwave filter system in on-road testing. The conclusion of the FY 2001 on-road diesel vehicle demonstrations will provide the answer to that question. Positive results will lead to product development partnerships with exhaust system suppliers, engine builders, or vehicle manufacturers. These strategic partnerships can move this technology to integration into a total commercial diesel exhaust emissions control system.

References

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Figure 1: Ford F-250 7.3 on-road test vehicle

Figure 2: Test apparatus on the exhaust of the Ford Truck

Figure 3: Volkswagen Jetta on-road controlled test-track vehicle